Causative factors for changes in total factor productivity of Japanese agriculture under the era of climatic uncertainty

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Abstract

The present study analyzed causative factors on TFP growth in Japanese agriculture. The regression analysis with consideration of correlation between factors demonstrated that fertility of farmland, farmers' physical ability, economies of scale, knowledge capital accumulated by research and development activities, public capital for irrigation, drainage and farmland consolidation and climatic changes significantly affected to TFP change. Since most of these factors are expected to decline in the future without further deregulation for introducing new comers, enlarging farm management area and asset management for keeping public capital, agricultural TFP cannot be improved in the near future in Japan.

Keywords: fertility of farmland, human factor, scale economies, public capital stocks, knowledge capital stocks, technological progress, Total Factor Productivity

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1. Introduction

The Japanese agriculture is decreasing its production because of aging of farmers, an increase in pressure of import products and changes in eating habits of consumers. In addition to these pressures, a climatic change may influence productivity of crops especially in southern part of Japan. To maintain agricultural production, it is important to improve total factor productivity (TFP) which represents comprehensive efficiency of production. Agricultural policy should consider these causative factors. In this sense, empirical studies on this subject are highly needed in Japanese agriculture.

Denison (1979) analyzed the causative factors of TFP growth in the US economy and found that economies of scale are one of the most significant factors among other factors. After his work, many previous studies analyzed agricultural TFP growth and causative factors. Research and development (R&D) activities were revealed to be one of the common factors for an increase in agricultural TFP (Alene, 2010; Pratt, Yu and Fan, 2009; Kuroda, 1989, 1995). Public investment was found to increase agricultural TFP in Thailand (Suphannachart and Warr, 2010) and in China (Chen, et al., 2008). Thirtle, Piesse and Schimmelpfennig (2008) showed that economies of scale are the dominant factor to increase TFP. Jayasuriya (2003) proved that soil quality was an important factor in technological improvement in Sri Lanka. Astorga, Berges and FitzGerald showed that the human capital played an important role in TFP growth of Indonesian agriculture. Salim and Islam (2010) concluded took climate change into account as an impact factor on TFP change in Australian agriculture. Unfortunately, there are a few empirical studies on the causative factors of TFP in Japanese agriculture.

The present study aims to measure impacts of causative factors to Japanese agricultural TFP. Several factors, such as fertility of farmland, human factor, economies of scale, public capital, the R&D activities and climatic change, are considered as explanatory variables for TFP growth. Different regression analyses are applied to prove influences of these factors with consideration of serial correlation and multi-linearity among explanatory variables.

Next section explains measurement method for TFP of agriculture and causative factors for estimation of the model by referring to previous studies. Third section shows the results of estimation. By using estimated model and some simulation results, policy implications are discussed in the fourth section. Final section provides summary and conclusion of this study.

2. Methods

2.1 Method for measuring TFP

This study used the Tornqvist index to measure TFP growth in Japanese agriculture. This index is flexible for the case of biased technological progress, because it can be derived from the trans-log production function (Kuroda, 1985). Since Japanese agriculture has achieved capital intensive technological progress (Kuroda, 1989), the normal TFP index calculated by the Solo’s residue with assuming neutral technological progress is problematic.

The Malmquist index derived from the data envelope analysis is employed in recent empirical studies, but this method needs enough sample size for estimation and is suitable for the individual farmers' data. This paper treats aggregate data on agricultural production, so it uses Tornqvist index rather than other indexes with consideration of the sample size and contents of data. This paper treats aggregate data on agricultural production, so it uses Tornqvist index rather than other indexes with consideration of sample size and contents of data.

Takayama and Takahashi (2010) modified data on total amount of input factors by considering part-time farmers and farmland and measured changes in the agricultural TFP by calculating the Tornqvist index. The estimation of TFP is owed to their work. The Tornqvist index used here is:

$$\ln(TFP_t / TFP_{t-1}) = \left[\ln(Y_t) - \ln(Y_{t-1})\right] - \sum_i 0.5(\beta_{it} + \beta_{it-1})\left[\ln(X_{it}) - \ln(X_{it-1})\right] \qquad (1),$$

where suffixes t and i respectively show year and the kinds of input factors, such as labor, capital, farmland and intermediate inputs like fertilizer. The left hand side of this equation shows logarithm value of the annual change in TFP. Y is the gross production of agriculture, and Xi is the i-th input factor used for production. β_i is the share rate of the i-th factor. Since the production structure is assumed to follow homogeneous production function, β_i is calculated from the cost share rate which is more suitable for the case of aggregated data (Fukao and Miyagawa, 2008).

If the biased technological progress is taken into account, β_i in Eq. (1) changes annually. On the other hand, if technological progress is neutral for each input, $\beta_{it} = \beta_{it-1}$ and Eq. (1) results in the Solo’s residue that is derived from the Cobb=Douglass production function.

2.2 Analysis on causative factors

As shown by the previous studies mentioned in the former section, several causative factors on TFP growth can be listed up. After considering of situations of Japanese agriculture and availability of statistical data, this study remarked six factors, i.e. human factor, fertility of farmland, public capital for irrigation, drainage and consolidation of farmland, the research and development (R&D) activities and climatic change. These factors regress to the TFP growth to prove relation and to measure degree of relation.

The model to be estimated is as follows.

$$\ln(TFP_t) = \phi_0 + \sum_j \phi_j \ln(Z_{j,t}) + \varepsilon_t \qquad (2).$$

Here, Z is the candidates for causative factors, and the suffix j shows the kinds of factors as explain later. ϕ is a parameter to be estimated and and ε is the error term. The log-log equation was employed here because the parameter to be estimated corresponds to the elasticity value of TFP with respect to each factor. In general, there may be high serial correlation between ε_t and ε_{t-1}, and serious mutual correlation among some causative factors. If so, the estimation results on ϕ would have some biases. In order to treat these problems, the regression model with first-order auto-regressive errors (AR1), and the structure equation model (SEM) are used in addition to the ordinal least square (OLS) model.

The working hypothesis behind causative factors is as follows.

(i) Human factor

Productivity of agricultural production highly depends on farmers' personal ability, such as skills, knowledge, and physical ability. Skills and knowledge can accumulate according to their age through experiences of agricultural production. Also, these can be improved by education as human capital. On the other hand, their physical ability decreases according to their age. Unfortunately, there is no information of farmers education background to measure the stocks of human capital of farmers. Hence, this study uses average age of kernel farmers who mainly engage in agriculture at age from 16 to 59 year old (*AGE*). If influence of *AGE* on TFP is positive, it shows accumulation of skills and experiences. If such influence is negative, it shows degradation of physical ability of farmers. The definition of *AGE* is:

$$AGE = \left(22.5 \cdot N\_Farm_{16-29} + 44.5 \cdot N\_Farm_{30-59}\right) / \left(N\_Farm_{16-29} + N\_Farm_{30-59}\right) \quad (3).$$

Here, *N_Farm* is the number of farmers who mainly engage in agriculture. Suffixes 16-29 and 30-59 mean the range of the age, and 22.5 and 44.5 are average of these age ranges. Note that this variable does not increase even if number of farmers who are over 60 year old increases.

(ii) Fertility of farmland

Fertile farmland can produce more crops with less fertilizer, so fertility of farmland increases agricultural TFP. Fertility can be changed by soil management and the frequency of planting. Unfortunately, there is no direct variable on fertility level for all farmland in Japan. This study uses the farmland utilization ratio which is calculated by:

$$RU = A\_Planting \,/\, A\_Farm \qquad (4),$$

where *A_Planting* is the total area of planting and *A_Farm* is total area of cultivated farmland. If the usage rate of farmland lowers, farmers would use fertile farmland and farmland with better geographical condition preferentially, and TFP of the all Japan would be raised.

Hence, small *RU* is expected to result in high TFP.

(iii) Economies of scale

Economies of scale inhered in the production structure would make the TFP increase. If so, the TFP will increase chronologically in proportion to the enlargement of the management scale of each farmer. In fact, large scale farmers in management area produce crops with less costs ('Cost Research of Rice', Ministry of Agriculture, forestry and fishery). In order to represent this factor, the average management area (MA) is considered to be the candidate. It is calculated by:

$$MA = A\_Manage \,/\, A\_Farm \qquad (5),$$

where *A_Manage* is the total area of farm management and *A_Farm* is the total area of farmland. This variable is the average of all Japan. The high value is expected to high level of economies of scale and relates to TFP in the positive way.

(iv) Public capital

The public capital stock corresponds to the amount of irrigation and drainage facilities and consolidated farmland. Irrigation and drainage facilities can increase the unit-production and reduce the operation costs of water distribution. Consolidated farmland can raise the working efficiency of farm machinery. Hence, the accumulation of public capital stock increases TFP. Considering construction process, *KG* influences TFP with at least one-year lag because of the gestation period.

KG is accumulated by the public investment, so the capital stock is defined by perpetual inventory (PI) method as follows (Kunimitsu, 2012).

$$KG = \sum_{tt=t}^{t-NR} IGR_t + \sum_{tt=t}^{t-NC} IGC_t + \sum_{tt=t}^{t-NF} IGF_t \qquad (6),$$

where t and tt are respectively year and year control parameter. *IGR*, *IGC* and *IGF* are public investment for reservoir, public investment for canal system, and public investment for farmland consolidation, respectively. *NR*, *NC* and *NF* are life time of facilities for reservoir, canal system and consolidated farmland.

(vi) Research and development (R&D) activities

Investment for R&D can provide new variety of crops and new technique for production, leading high TFP. According to the empirical studies on Japanese agriculture, the productivity of Japanese agriculture has been increased by R&D (Kuroda, 1989, 1995). In general, R&D activity has some time lag to activate in the real world. Once it is activated, it can increase production for several years, but it will be worn out for some years and become old-fashioned. By considering these features, this study uses knowledge capital stock rather than R&D investment itself.

The knowledge capital stock (*KK*) was estimated based on the method of the Policy Research Institute on Science and Technology (PRIST, 1999). The equation for *KK* is:

$$KK_t = (1-\theta^G)KK^G{}_{t-1} + R\&D^G{}_{t-Ng} + (1-\theta^F)KK^F{}_{t-1} + R\&D^F{}_{t-Nf} \qquad (7)$$

Here, the prefixes of *G* and *F* mean public and private, respectively. *R&D* is the investment for R&D activities. θ and *N* are the obsolescence rate of knowledge and time lags representing the time in which developed technology spread to the commercial fields, respectively. According to the questionnaire survey conducted by the PRIST, θ_g=0.075, θ_f=0.101, N_g=9 years and N_f=6 years. By using these parameter values and estimation of *KK* from 1973 to 1997 by PRIST, this study estimated *KK* from 1998 to 2006.

(vii) Climatic change

Agricultural production is highly influenced by the climatic conditions, such as temperature, sunshine and rain fall. These influences are unexpected impact for farmers, so it is difficult for them to prepare for such impact. Hence, TFP of agriculture also fluctuates because of climatic change. In order to consider such impact, this study considers five climatic variables, such as average temperature of whole country from October to March (*TempW*), monthly average temperature in Hokkaido region in August (*TempH8*), monthly average temperature in Tohoku region in August (*TempT8*), cumulative total precipitation in September (*Rain9*), and cumulative daily sunshine hours from September to December (*Solar912*). Among these, *TempW* relates to winter vegetable production, *TempH8* and

TempT8 relate to flowering of rice and summer crops, and *Solar912* affects ripening of crops. Therefore, these four variables are expected to affect TFP change in positive way. On the other hand, Rain9 can represent the disaster caused by typhoon, so this variable is expected to affect TFP in negative way. In order to introduce these variables into analysis, the climatic index (*CI*) is composed as follows.

$$CI = TempW + TempH8 + TempT8 - Rain9 + Solar912 \quad (7).$$

2.3 Data

The data for measuring TFP of agriculture were provided by Takayama and Takahashi as already mentioned. Their work covered (i) total agricultural production, including added value and intermediate input costs; (ii) the private capital stocks related to agricultural machinery, buildings, livestock, and the stocks of fruit trees; (iii) the service costs of the private capital stocks; (iv) labor costs and labor inputs; and (v) farmland inputs. A detailed explanation of data composition can be found in their paper.

Variables related to the causative factors were gathered from several sources shown in Table 1. All of these were chronological data published by the public organization. The capital stock was calculated from investment data which were in the public statistics. In terms of total number of farmers, some modifications were needed to obtain consistent data. These data used for variables of economies of scale were discontinuous at the moment of the agricultural census after 1990 because of a change to investigation method. It is not realistic that the trend of the number of farmers changes greatly at a certain year and becomes discontinuous. To adjust such discontinuous tendency, the growth rate at the discontinuous year was replaced by the rate of previous year by assuming that the number of farmers changes continuously.

Table 2 shows basic statistics on variables for estimations. Table 3 is the correlation ratio of causative factors. As shown by Table 3, there may be serious multi-collinearity, and consideration of covariance among explanatory variables is needed. Especially, it is thought that the correlation ratio between *MA* and *KK* is too high to be free from such problems. Hence, this study estimates the model with cross term of ln(*KK*)・ln(*MA*) in addition to separate type. The cross term shows that the more knowledge capital can increase the elasticity of TFP with regard to *MA*.

<Insert Table 1, Table 2 and Table 3>

3. Results

3.1 Estimations of TFP

Figure 1 shows the chronological change in TFP estimated by Eq. (1). This result is the same as Takayama and Takahashi (2010). The chronological trend of agricultural TFP is increasing with showing some fluctuations. Even so, it is clear that the agricultural TFP continuously has grown as time goes by.

<Fig. 1 >

3.2 Causative factors of the increase in TFP

Table 4 shows the estimation results of Eq. (2). The M0 (model 0) is the case of using all variables separately, whereas the M1 (model 1) uses the cross term of KK and MA. OLS is the ordinal least square method, AR1 is the regression model with first-order auto regressive errors and SEM is the structure equation model for consideration of correlation among factors.

The fitting indexes of R2, GIF and RMSEA indicate good performance of these models. Most of the estimation coefficients, except for that of KK in M0, were significant as compared to the t-statistic value at the 1% level of error. The negative estimated parameter of KK, which is expected to have positive correlation, probably comes from the multi-collinearity problems, so the M1 is thought to be more suitable. Although there are some insignificant results in this estimation, causative factors considered here, in total, explains most of a chronological increase in TFP.

The Durbin-Watson statistics in the OLS estimations and the estimated parameter of ρ that represents correlation between εt and εt -1 show that there were not serious problems caused by the serial correlation. The models estimated without serial correlation are seemed to be better than that by the AR1 method. However, as shown in Table 3, the estimations by the OLS method may be biased by the multi-collinearity problem. The estimations of the SEM managed such a problem by assuming covariance structure between factors. The results of SEM showed that estimated variance-covariance matrix was significant in all elements. Hence, the estimations by the SEM are more suitable than other methods. However, differences in estimated coefficients among three methods were not so large, so these estimations can prove the affects of causative factors on TFP changes.

The elasticity values of TFP with respect to each causative factor were calculated by estimations of M-1S. That is, fertility of farmland (*RU*) is -0.3 to -0.4, human factor (*AGE*) is -3.8 to -4.2, economies of scale (*MA*) is 0.1 to 0.2, R&D (*KK*) is 0.03 to 0.13, and public capital (*KG*) is 0.2. Among these causative factors, elasticity of human factor was strongest, and the next strongest factor was fertility of farmland. Other factors were relatively low, though significant.

<Table 4 >

Fig. 2 shows the contribution degree of each factor calculated from the M1-S for every decade. The public capital stock greatly influenced the growth of TFP in all periods, although the elasticity of public capital was not the highest. This is because high elasticity factor like MA and AGE has not been changed as high as public capital. However, the contribution degree of the public capital has decreased through estimation period, even though its contribution is still large. This change is because the growth rates of public capital decreased after 1970. The decrease in the contribution degree of the public capital was particularly drastic in the 2000s because the budget for public investment, which was the main driving force of the accumulation of public capital, was cut after 2001.

The contribution degree of fertility of farmland was decreased after the 1970’s. The human factor made agricultural TFP decrease till the 1990’s, but its contribution degree became positive in the 2000’s. Since Japanese economies have experienced long term recession after the bubble economic burst in 1990, new comers to agricultural sector probably increased a little bit and resulted in an increase in TFP.

The knowledge capital stock recently became stronger in its contribution degree because the growth rate of knowledge capital accelerated even in the 2000's. It can be said the R&D activities play an important role in agricultural growth.

The knowledge capital stock recently became stronger in its contribution degree. Since the growth rate of knowledge capital accelerated increased even at the 2000’s, it can be said the R&D activities plays an important role in agricultural growth. The economies of scale also increased in its contribution degree to TFP growth, and such increase was high in the 1990's. This tendency declined a bit in recent years.

< Fig.2>

4. Discussion and policy implication

Table 5 shows the prediction results of TFP in 2030. In this prediction, three scenarios are considered as follows.

BAU (Business as usual): The level of each causative factor is estimated according to the chronological trend from 1981 to 2005.

Case 1 (Increase in new comers): The human factor represented by AGE can decrease by an increase in new comers, such as stock corporations and agricultural production legal person. In this case, the level of AGE is assumed to be the same as the level of 1980 by going back to the time quarter of a century ago.

Case 2 (Acceleration of management areas): Management area of one farm household is expected to increase by 100 % as compared to BAU case.

Case 3 (Asset management for public capital): The public capital can stay at the higher level because of the asset management measures which prolong life time of old facilities and reduce construction costs by recycling usable old materials. The asset management measure is just starting in Japan, and difference in public capital assumed in this case will be revealed in the near future.

Case 4 (All together of above cases)

As shown by the BAU case, fertility of farmland is improved by a decrease in RU, making TFP increase. Economies of scale represented by management area of a farm household increase by 46 %, making TFP increase. The knowledge capital cumulated by the research and development activities increases a lot according to the recent trend, making TFP increase.

On the other hand, the human factor is degraded because of aging of key farmers, making TFP decrease. The public capital decreases by almost half, because of budget cut in public investment. The public investment for agriculture in 2011 is about 20 % of the level in 1995. This makes TFP level lower. Consequently, TFP in 2030 increases a little, and this means that Japanese agriculture can grow only a little bit. Such predicted level is 70 % of expected TFP estimated by the chronological trend. As compared to the former growth rate of TFP, this little improvement in BAU indicates a sort of crisis in Japanese agriculture that is facing high pressure of imported food in the market.

By introducing new comers in agricultural sector and avoiding the aging of the kernel farmers, the TFP level can be increased by 17 % than BAU case. Also, by enlarging management area of the farm household to emerge economies of scale, the TFP can be increased by 21 %. Even in such acceleration, management area of Japanese farmers is still far smaller than US farmers, so such acceleration is not a dream. To achieve these situations, further deregulation on farmland law and other agricultural legal system is highly needed.

The asset management measure prolonging life time of old public facilities improves TFP by 9 % than BAU case. Of course, if the government can increase the budget for the public investment, agricultural TFP will increase more. However, considering serious deficit in the national accounts in Japan, such budget increase would be difficult, so the government, at least, is asked to enforce the asset-management measures steadily.

In case 4, combination policy on deregulation and asset management improves TFP by 43 %. Actually, such increase rate is almost the same as trend prediction on TFP without any consideration of changes in causative factors. From this fact, it is impossible to keep the speed of agricultural TFP without further deregulation and asset management measures in Japanese agriculture. In addition to this, to keep the growth rate of investment of R&D is important. Actually, to increase knowledge capital by 4.9 times higher than present level needs an annual growth rate of investment in R&D in 3 % per year which has been achieved in the past. This rate is supposed in all simulation cases, so if the R&D activities will be slowed down, even deregulation and asset management measures cannot keep agricultural TFP progress.

4. Summary and conclusions

The present study measured chronological changes in the TFP of general agricultural production. An empirical estimation was conducted to show the causative factors of the TFP growth, including fertility of farmland, human factor, economies of scale, public capital stocks like irrigation facilities, knowledge capital stocks that can be accumulated through research and development, and climate condition.

The results demonstrated that the agricultural TFP has increased from the 1960s to the 2000s. This improvement of TFP has a positive relation with fertility of farmland, economies of scale, human factor showing physical ability of farmers represented by average age of kernel farmers, public capital stocks, and knowledge capital stocks. The influence of the public capital stocks was great as compared to other factors, but the influence of other factors became more in recent decades. Although the elasticity of TFP growth with respect to public capital was the same, the influence degree of public capital decreased, because the growth rates of this capital stocks decreased gradually. The climate index significantly relates to the TFP, but its affect is not so high compared to other factors.

Future prediction by using above estimations indicated that the deregulation and asset management measure is highly needed to introduce new comers to agricultural sector, to accelerate an increase in management area of one farm household and to keep irrigation and drainage facilities and consolidated farmland in good condition.

Finally, several issues remain. The estimation period needs to be expanded in order to analyze more recent events. Regional differences in TFP and its causative factors are also interesting for rural revitalization policy.

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Table 1 Data and sources.

Variables	Unit	Contents	Source
N_Farmer	person	Number of professional farmers by ages	Agricultural Census (Ministry of Agriculture, Forestry and Fishery)
N_FHouse	household	Number of farm household including prttime farmers	
A_Manage	ha	Management areas for cultivation	Statistics on cultivated acreage and planted area (Ministry of Agriculture, Forestry and Fishery)
A_Farm	ha	Farmland areas	
A_Planting	ha	Planting areas of farmland	
KG	million yen	Public capital of irrigation, drainage and consolidated farmland	Kunimitsu (2012) based on "Japans Social Overhead Capital
$I_{R\&D}$	million yen	Investment for research and development	Reprot on the Survey of Research and Development (Ministry of Internal Affairs and Communications)
Temp-W	degrees Celsius	Average temperature of whole country from October to March	Iizumi et al.(2010) "Climatic Change"
Temp-H8	degrees Celsius	Monthly average temperature in Hokkaido region in August	
Temp-T8	degrees Celsius	Monthly average temperature in Tohoku region in August	
Rain9	mm/mon	Accumulated Total Precipitation in	
Solar-912	MJ/m^2	Cumulative Daily Total Solar Radiation from September to December	

Table 2. Basic statistic values of explanatory variables.

Factors	Variables	Unit	Average	Std. dev.	minimum	maximum
Fertility	*RU*	Ratio	1.046	0.09	0.94	1.289
Human factor	*AGE*	Year old	42.56	1.11	39.78	43.68
Economies of scale	*MA*	100 m^2/household	124.99	17.73	102.33	158.90
R&D	*KK*	million yen	439,103	332,807	73,119	1,141,282
Public capital	*KG*	million yen	29,546,400	19,637,400	3,328,657	64,002,800
Climatic change	*CI*	Ratio	−0.015	0.270	−0.800	0.440

Table 3. Correlation ratio between explanatory variables.

	RU	*AGE*	*MA*	*KK*	*KG*	*CI*
RU	1					
AGE	−0.89	1				
MA	−0.84	0.94	1			
KK	−0.75	0.80	0.95	1		
KG	−0.80	0.89	0.99	0.98	1	
CI	0.09	−0.12	−0.17	−0.22	−0.20	1

Table 4. Estimation results of influences of causative factors

Explanatories	OLS		AR1		SEM	
	M0-O	M1-O	M0-A	M1-A	M0-S	M1-S
C	0.057	5.162	0.165	5.026	3.583	4.977
	(0.02)	(8.03***)	(0.07)	(7.27***)	(2.13**)	(8.08***)
RU	-0.387	-0.362	-0.385	-0.361	-0.251	-0.313
	(-3.37***)	(-3.11***)	(-3.52***)	(-2.95***)	(-1.61)	(-3.00***)
AGE	-0.083	-0.095	-0.081	-0.088	-0.094	-0.096
	(-2.70**)	(-3.10***)	(-2.73***)	(-2.72***)	(-3.30***)	(-3.37***)
ln(MA)	1.34		1.297		0.314	
	(1.99*)		(2.02**)		(0.92)	
ln(KK)	-0.022		-0.018		-0.011	
	(-0.37)		(-0.32)		(-0.11)	
ln(KK)･ln(MA)		0.014		0.014		0.009
		(2.72***)		(2.62***)		(2.81***)
ln(KG)	0.13	0.179	0.129	0.169	0.234	0.207
	(1.88*)	(2.80***)	(1.96**)	(2.50**)	(3.27***)	(3.95***)
CI	0.041	0.049	0.041	0.046	0.046	0.048
	(2.41**)	(2.92***)	(2.68***)	(3.08***)	(2.89***)	(3.22***)
ρ			0.054	0.149		
			(0.31)	(0.91)		
R2	0.976	0.974	0.976	0.974	0.974	0.974
GFI					0.973	0.971
RMSEA					0.024	0.081
D.W.	1.85	1.7	1.95	1.99		

Note: 1. RU is the usage rate of farmland representing fertility of farmland; AGE is the average age of kernel farmers under 59 year old representing physical ability of farmers; *MA* is the average farm management area of an individual farmer representing economies of scale; *KK* is the knowledge capital stock accumulated by research and development activities; KG is the public capital stock; and CI is the climate condition representing temperature, rain and solar radiation.

2. OLS is the ordinarily least square estimation, AR1 is the first-order autoregressive error estimation and SEM is the structural equation model with assuming covariance structure.

3. The values in parentheses are the t-statistic values, and ***, ** and * indicate the significance level of 1%, 5% and 10%, respectively.

Table 5. Prediction of future TFP level

	BAU Est. by Chrono. Trend	Case 1 Promotion of new entry	Case 2 Accelerating management areas	Case 3 Asset management	Case 4 All together
RU (30/03)	0.88	0.88	0.88	0.88	0.88
AGE (30/03)	1.01	0.97	1.01	1.01	0.97
MA (30/03)	1.46	1.46	1.46	1.46	1.46
KK (30/03)	4.88	4.88	4.88	4.88	4.88
KG (30/03)	0.58	0.58	0.58	0.73	0.73
TFP ('03)	128				
TFP ('30)	133	149	155	139	182
TFP (30/03)	1.04	1.17	1.21	1.09	1.43

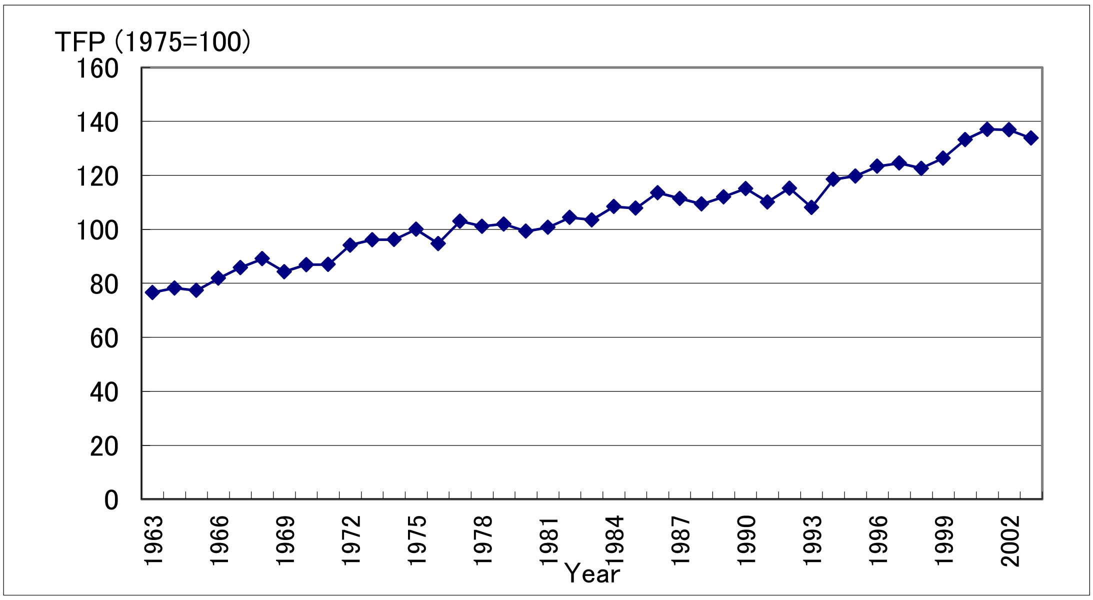

Fig. 1 Chronological change in TFP of Japanese agriculture

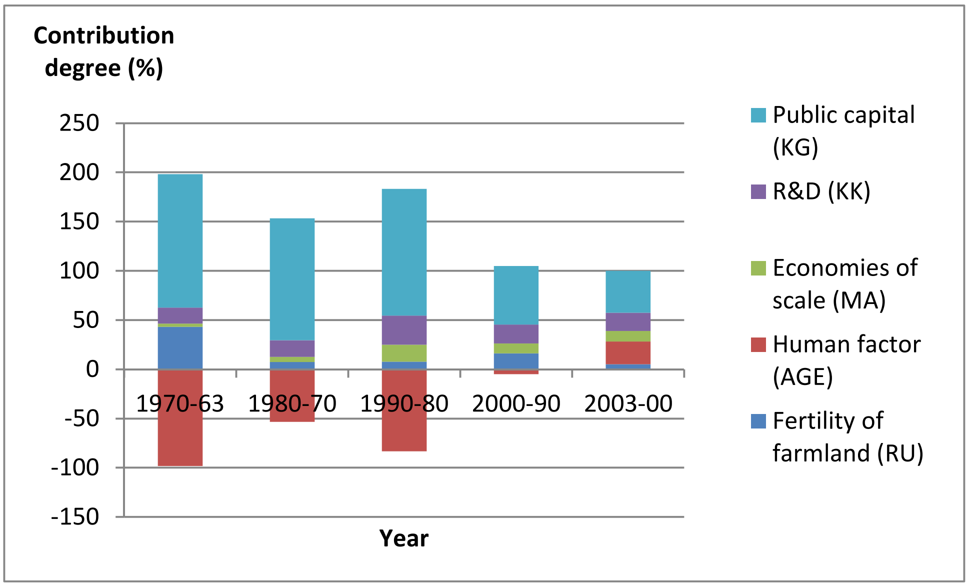

Fig. 2 Contribution degree of each factor to the TFP growth by decades